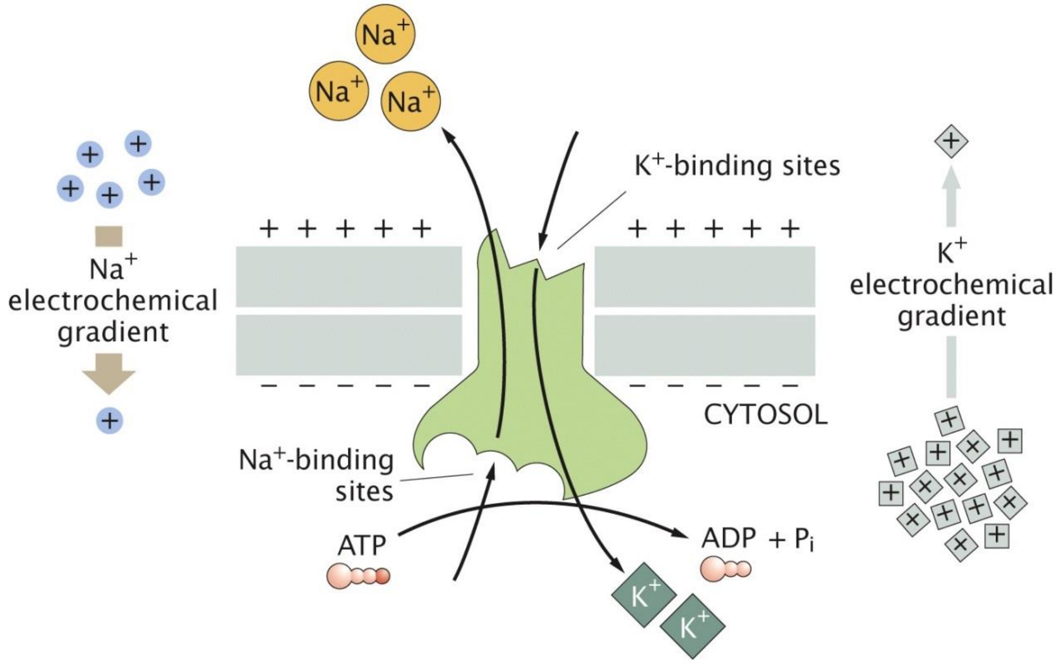
Steady State and Membrane Resting Potential

The previous PDF handout points out that since the Nernst potential, $V_i^{Nernst} \neq \Delta V$ is not equal to the membrane potential there are current flow of ions of the amount, $I_i = \left(V_i^{Nernst} - \Delta V\right) / R_i$, where ions, Na^+, K^+, Cl^-, into or out of the cells. The flow of ions will change the concentration of ions **inside** the cell, $C_{Na^+,in}, C_{K^+,in}, C_{Cl^-,in}$. This should lead to a change in the membrane potential of ΔV. But it is well known that a **living cell** maintains a **constant membrane potential** of $\Delta V \sim -60mV$.

USEFUL QUESTIONS you should know how to answer: 1) Why do the flow of ions **do not significantly change** the ion concentrations **outside** the cell?; 2) How does the cell maintain a constant membrane potential $\Delta V \sim -60mV$.

Na^+/K^+-ATPase ion pump pumps **Na^+ out** of the **cell** and **K^+ into** the **cell**.



As illustrated in the diagram above, **Na^+/K^+-ATPase** is a **protein** that pumps **two K^+** potassium ions **into** the cell, and **three Na^+** sodium ions **out** of the cell, per cycle. This compensate for the leak current and of **K^+** potassium ions **out of** the cell, $I_{K^+}^{ohmic} < 0$, and of **Na^+** sodium ions **into** the cell, $I_{Na^+}^{ohmic} > 0$, as shown in question 2 of assignment 8. This maintains **constant** ion **concentrations inside** the cell, $C_{Na^+,in}$, $C_{K^+,in}, C_{Cl^-,in}$, which in turns means that the membrane **resting potential** remains constant at $\Delta V \sim -60mV$. In physics we say that the membrane is in a **steady state**. The image on the **next page** illustrate what happens in a living cell:

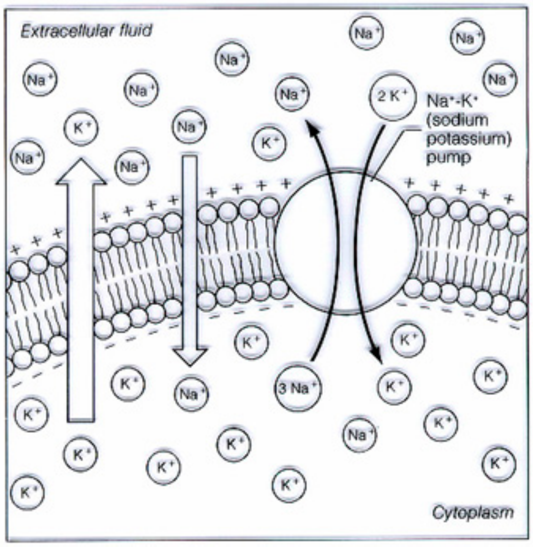


Figure shows how a **living** cell maintains a steady state membrane potential of $\Delta V = -60mV$

IMPORTANT POINT: membrane is **not** at **equilibrium.**

Donnan Equilibrium: When a cell dies the Na^+/K^+-ATPase stops pumping ions, but the cell will continue to leak of **K⁺** potassium ions **out of** the cell, $I_{K^+}^{ohmic} < 0$, and of **Na⁺** sodium ions **into** the cell, $I_{Na^+}^{ohmic} > 0$. This will change the ion concentration inside the cell and will change the membrane potential ΔV. This will continue until the all Nernst potentials equal the membrane potential: $\Delta V = V_{Na^+}^{Nernst} = V_{K^+}^{Nernst} = V_{Cl^+}^{Nernst}$. When this happens the cell will be at equilibrium, known as **Donnan equilibrium.** A typical Donnan equilibrium potential is $\Delta V = -10mV$.

QUESTION YOU SHOULD KNOW HOW TO ANSWER:

1) Examine the current leak equation, $I_i = \left(V_i^{Nernst} - \Delta V\right) / R_i$, to explain why the current of ions is zero at Donnan equilibrium.

2) Given that charges usually flow until the electric potential difference is **zero**, **why** do you think the Donnan potential is not zero, $\Delta V \neq 0$?

HINT for one of the question: Lipid molecules that make up membranes are usually charged, and negatively charged **proteins** inside (intracellular) cells cannot permeate to the extracellular fluid outside the cell (see figure below).